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ABSTRACT

Recently, knowledge of the mechanisms of visual-spatial attention has improved due to studies employing single cell recording with alert monkeys and studies using performance analysis of neurological patients. These studies suggest that a complex neural network including parts of the posterior parietal lobe and midbrain are involved in covert shifts of visual attention. This paper describes two experiments employing the dual task technique to determine if covert visual orienting can take place while a person's attention is engaged in a language processing task. Results show clear evidence of interference between the two tasks suggesting a common system. The results also indicate that whatever is common to the two tasks does not have the same anatomical location as found for visual spatial attention. Previous work in cognitive psychology has also proposed a dissociation between the alerting and selective aspects of attention. In agreement with this dissociation the present study found that omitting any warning signal worsened performance for left-sided patients. These two patterns were also found in normals when we compare blocks run at a high state of alertness with those run at lower levels of alertness. These results support suggestions of a right sided bias for alerting but show that it is not the cause of the attentional selection deficit often reported in right parietal patients. A hierarchical distributed network is proposed to accommodate these data. (Author/JAZ)

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Cognitive Science Program

TEACHING ATTENTION SYSTEMS: A COGNITIVE-ANALYTICAL ANALYSIS

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Previous work in cognitive psychology has also proposed a dissociation between the alerting and selective aspects of attention. In agreement with this dissociation the present study found that omitting any warning signal worsened performance for left sided patients. These two patterns were also found in normals when we compare blocks run at a high state of alertness with those run at lower levels of alertness. These results support suggestions of a right sided bias for alerting but show that it is not the cause of the attentional selection deficit often reported in right parietal patients. A hierarchical distributed network is proposed to accommodate these data.

Isolating Attentional Systems: A Cognitive-Anatomical Analysis¹

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ABSTRACT

Recently our knowledge of the mechanisms of visual-spatial attention has improved due to studies employing single cell recording with alert monkeys and those using performance analysis of neurological patients. These studies suggest that a complex neural network including parts of the posterior parietal lobe and midbrain are involved in covert shifts of visual attention.

1

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Is this system an isolated visual attentional module or is it part of a more general attentional system? Our studies employ the dual task technique to determine if covert visual orienting can take place while a person's attention is engaged in a language processing task. We find clear evidence of interference between the two tasks suggesting a common system. However, the results also indicate that whatever is common to the two tasks does not have the same anatomical location as found for visual spatial attention.

Previous work in cognitive psychology has also proposed a dissociation between the alerting and selective aspects of attention. In agreement with this dissociation the present study found that omitting any warning signal worsened performance for patients with right sided lesions, but improved performance for left sided patients. These two patterns were also found in normals when we compare blocks run at a high state of alertness with those run at lower levels of alertness. These results support suggestions of a right sided bias for alerting but show that it is not the cause of the attentional selection deficit often reported in right parietal patients. A hierarchical distributed network is proposed to accommodate these data.

2

A fundamental problem of attention is to understand how the unity of conscious experience is related to the many levels of selectivity involved in processing external events. The amount of information of which we are aware at any moment seems remarkably limited, yet it is often efficiently selected from a vast array of input. We are generally unaware of the details of the selection, but without it our subjective experience could not remain unified.

The complexity of these issues has made it desirable to divide the study of attention into subareas. One traditional distinction is between the arousal or alerting aspect of attention and the selective aspect (see Kahneman, 1973). In part this separation is cognitive, corresponding to the difference between the mechanisms allowing us to maintain awareness of our environment and those specifying the content of awareness. In part, it arises from a distinction between subcortical arousal systems (e.g. midbrain and thalamic reticular arousal systems) and the sensory systems that provide specific information about stimuli. In this sense the distinction is at once both cognitive and anatomical.

Within the study of selective attention it has also been traditional to deal with subareas based either on the modality of input (e.g. auditory, visual) or the type of information or cognitive system involved (e.g. language or spatial).

In recent years a more detailed anatomical and physiological analysis of attention has developed within the domain of selection of visual spatial information (Mountcastle, 1978; Posner, 1980; Wurtz, Goldberg & Robinson, 1980). This work involves studies of alert monkeys and of normal and brain injured patients orienting to visual events. Since no overt changes (e.g. eye movements) need occur in order for there to be evidence of selection at the attended location it is possible that mechanisms revealed by these studies may serve as a model for understanding attention in general.

At the level of computations one can view a shift of visual attention as involving three more elementary operations isolated from chronometric studies. The first is disengaging from the current focus of attention. It is a well established principle that the depth of commitment to one task influences the time to switch or disengage from that task (LaBerge, 1973). This principle underlies much of the use of secondary tasks to measure attention demands (see Kerr, 1973 for a review).

The second operation involves a movement of attention from its current focus to the new location. There is some reason to believe that this movement is analog in the sense of passing through the intermediate locations (Shulman, Remington & McLean, 1978; Tsai, 1983; Ullman, 1985), but this is by no mean settled (Hughes and Zimba, 1985; Remington and Pierce, 1984; Shulman, Wilson and Sheehy, 1985). The move operation could be similar to the operation involved in mental

rotation and image scanning (Koslyn, 1980, Pinker, 1980, Shepard, 1978).

Finally the subject must engage the new target. The engage operation is likely to differ depending upon the task required. Some processing (e.g. the registration of features or the lookup of highly familiar responses) may take place without engaging attention (Marcel, 1982; Treisman & Galade, 1980). However, it appears necessary for attention to be at the target in order for an arbitrary speeded response of maximum efficiency to occur. Thus faster responses and higher d's are reported to events which occur at locations to which attention has been cued (Bashinski & Bachrach, 1980; Downing & Pinker, 1985; Posner, 1980).

Each of these operations appears to be affected by a different form of brain injury. Damage to the parietal lobe can produce a severe deficit in the ability to disengage attention from a visual location, without any necessary loss in efficiency of the move or engage operation (Posner, Walker, Friedrich and Rafal, 1984). Although damage to the parietal lobe can leave the person unaware of stimuli contralateral to the lesion if visual attention is engaged elsewhere (Posner, Cohen and Rafal, 1982) the same visual location may show normal or near normal response, time when attention has been attracted there. This indicates that it is possible for the engage operation to be normal or near normal when the disengage operation is severely damaged. On the other hand, damage to midbrain areas related

to saccadic eye movements can produce a specific slowing of the move operation (Posner, Cohen and Rafal, 1982; Posner, Choate, Rafal and Vaughan, 1985).

These findings fit well with the single cell recording data from monkeys. The monkey studies have shown that the parietal lobe contains cells show in enhanced responses to stimuli in their receptive field when the animal is trained to attend to that location while maintaining fixation at another place (Murtz, Goldberg & Robinson, 1980). On the other hand cells in the superior colliculus appear to be much more closely related to attention when it involves eye movements.

The human data suggest that midbrain lesions can affect covert attention shifts, but the components affected are those highly related to the eye movement system. For example, it has been shown that lesions of the midbrain may increase the likelihood of attention returning to a visual location which has recently been examined either by a fixation or covertly (Posner, Choate, Rafal and Vaughn, 1985). Such a mechanism would have obvious importance in visual scanning.

Thus we can now define visual-spatial attention in terms of relatively precise cognitive operations and also say something about the anatomical locus of these operations. In this paper we use our knowledge of the visual-spatial attention module to study two general questions related to attention. First, is the module that subserves visual-spatial attention separate from other systems that subserve

attention or is it part of a more general system? If the latter, is the anatomy of the more general system distinct from the visual-spatial system? Second, does the operation of visual-spatial attention involve separate alerting and selection operations as suggested by cognitive theory? If so, can we define their anatomical substrate?

Experiment 1

Our strategy to explore these two issues was to assess the performance of patients with known deficits due to parietal lesions and groups of normal controls. To study the issue of whether visual-spatial attention is a separate module we had subjects perform a visual-spatial orienting task either by itself or combined with one of two secondary tasks. The secondary tasks were chosen in an effort to insure the use of separate input and output paths and quite different cognitive operations from those used in visual-spatial orienting. We then examine the ability of the patients and normals to time share the primary and secondary task. Suppose visual-spatial attention is a separate module. We would expect a general increase in reaction time due to interference with output or reliance upon some very general common resource. However, the advantage of a shift of attention to the cued location would be expected to remain present, since if visual-spatial is a separate module it could operate to shift

attention even when the subject was engaged in performing the secondary task. Suppose instead that the secondary task shares some of the same attentional mechanisms with visual-spatial attention. We would then expect to find interference with the covert shift of attention (e.g. invalid-valid RTs) as well as an overall increase in reaction time.

Our previous work has established that whenever patients are engaged visually they have a special difficulty in responding to invalid targets contralateral to the lesion. Suppose the secondary tasks engage attention by use of the same parietal system identified with spatial orienting. If that were the case, when a patient was attending to the secondary task there would be a specific loss in the ability to deal with invalid targets contralateral to the lesion. That is if the secondary task uses the parietal system we ought to see the usual sign of engagement of that system namely a specific deficit for contralateral targets. Thus, we can get information about the anatomical basis for any specific interference effect by asking whether the secondary task creates a specific deficit for invalid contralateral targets.

We thus have two indices of the separability of the primary and secondary task. The first has to do with whether the secondary task affects the advantage of valid over invalid RTs found when the primary task is performed alone. This index allows us to determine whether the two tasks involve the same or different cognitive components of

attention. The second index is whether or not the secondary task serves to produce a greater specific deficit for invalid contralateral targets. The second index tells us about whether engaging attention the secondary task involves the same anatomical system as attending to a visual location does.

The second issue to which this study is addressed has to do with the separability of alerting from directional or selective operations. Whenever an event is presented which can serve to cue attention to a location it can also serve as a warning signal to vary the level of alertness. In all our previous work we have held alertness constant by always introducing a cue. In the present study we arrange for blocks in which no cue is presented. In such blocks the subject must maintain alertness without the aid of a warning signal on each trial. It has been suggested that the basis of the parietal deficit depends upon a reduced alerting or hypoarousal of the affected hemisphere producing the observed deficit in dealing with contralateral stimuli (Heilman and Van Den Abel, 1979). If this is so omitting the alerting cue ought to increase the problem patients have with contralateral targets.

Method

Subjects/patients: Nine patients with unilateral parietal lesions were subjects in the phoneme monitoring experiment. In addition five of these patients were subjects in the backward counting experiment. Four patients (WK, JC, EA, and BI) had participated in previous experiments and their clinical conditions are described in Posner et al (1984) (Table 1). CT scans were available for diagnosis for all of the five new parietal patients. CT scans show a hypodense area in the parietal lobe (BB, KR), infarction in the parietal area (MF) or fronto-parietal-temporal area (RC), or hematoma in the temporo-parietal lobe (CC). Two of the left-parietal patients were aphasic (RC and BB). With the exception of RC whose age is 35 years, all other new patients were older than 60 years.

Control subjects: 16 subjects without documented neurological disorders served as controls for the parietal patients. Eight of the control subjects were in the age group of 19 to 35 years and were recruited from the staff of Good Samaritan Hospital and Medical Center or Portland State University and eight of the control subjects were elders in the age brackets of 60 to 75 years.

Tasks: In the single task condition, subjects were required only to detect the visual target and to depress a single key with the index

finger as quickly as possible. The basic experimental paradigm was similar to Posner, Walker, Friedrich and Rafal (1984). Subjects faced a cathode ray tube (CRT) 80 cm from the eyes. They were instructed to maintain fixation on a central box. Two peripheral boxes were present approximately eight degrees to the left and right of fixation.

Two types of single task blocks were used. In cued blocks one of the two peripheral boxes brightened for 300 millisecond. The onset of the cue was followed after an interval of 100, 500 or 1000 millisecond by a bright asterisk occurred on the cued side 80% of the time (valid trials) and on the uncued side 20% of the time (invalid trials) on the uncued side. In uncued blocks the cue was omitted and only the target occurred either 1100, 1600 or 2,000 millisecond after the previous response.

In the dual task condition one of two secondary tasks was added to the primary task. One secondary task involved phoneme detection. Subjects were required to monitor for the phoneme 'p' in a list of words. Specifically, subjects were played a tape with 30 lists of 20 words each. These lists were spoken by a native speaker at a word presentation rate of approximately one word per two seconds. Only nouns were used. In each list one to seven words began with the phoneme 'p'. Immediately, after the last word of a list was pronounced, the command 'stop' was given which indicated that the visual detection task was to be interrupted and that the last item of a list of words had been presented. After the 'stop' command, the

patient was asked how many nouns on the presented list of words had begun with the letter 'p'. This was followed by a silent interval of approximately three seconds within which the subject was required to report the number of words that started with the phoneme 'p'. After this, a 'ready' command was given indicating that the visual detection task was to be continued and that a new list of words was to be presented.

The backward counting task was similar. Each block of trials was initiated by a two digit number from which the patient counted backward by one. In the dual task blocks orienting trials were conducted during the counting process. After 15-20 trials a rest and new digit pair was given.

Performance on the phoneme monitoring task alone was ascertained in separate blocks for five of the patients.

Procedure - Each subject was run in all of the conditions in a single session. At the start of the session they were introduced to the phoneme or backward counting task. They then received either three blocks of no cue trials followed by three blocks of cued trials or the reverse (the order was counterbalanced across subjects). Each block consisted of 100 trials if no cues were involved and 300 trials for cued blocks. Within each set of three blocks and ABA design was used so that visual orienting alone came both before and after the dual task block.

The counting backward task was run on five patients prior to use of the phoneme monitoring task. This was done in a single session and only cued trial blocks were used.

13

Results

The main results of the experiment are in terms of reaction times for the spatial attention task when performed alone and in conjunction with the monitoring task. The median RTs for each condition was calculated for each subject. All RTs less than 100 millisecond or greater than 3,000 millisecond were excluded, but these represented less than 1% of the trials. Overall results were quite similar for the trials in which there was a 100 millisecond delay following the cue and for trials in which the delay was longer. Since 2/3 of the trials were run at the 100 millisecond interval and these trials are free of any eye movements they seem most appropriate for discussion. While the ANOVAs reported include all delay intervals we discuss the longer intervals only in those cases where interval interacted with other effects.

The overall data from the primary task with phoneme monitoring as the secondary task was cast into an two separate analyses of variance. One involved the patient groups and had side of lesion as the between subject condition and attention (focussed vs divided), cue (valid, invalid, no cue), visual field (ipsilateral vs contra lateral to lesion) and interval (short vs delayed) as the within subject variables. A second analysis involved only the control subjects and had age as the between subject variable (8 old and 8 young) with the

14

same set of within subject variable except that visual field was now left versus right. The set of data from the five subject who counted backward was also summarized but not analyzed statistically.

Figure 1 shows the valid and invalid trials for each of the

Insert Figure 1 here

four subject groups when doing the primary visual orienting task by itself. All four groups of subjects show an advantage of valid over invalid trials. Two facts merit further discussion.

First, both left and right sided patients show markedly larger advantage of valid over invalid trials when the target is contralateral to the lesion than when it is ipsilateral to the lesion (cue X side interaction $F(2,14) = 9.3; p < .01$). This has been previously reported (Posner, et al, 1984) and called the extinction like reaction time pattern, since it is similar to the clinical phenomenon in which patients miss contralateral signals when they occur simultaneously with ipsilateral signals (extinction). Left and right sided patients both show normal validity effects on the ipsilateral side but markedly larger effects on the contralateral side. Both groups of patients also show longer reaction times on the average on the contralateral side.

Second, the no cue condition generally gives RTs faster than the valid cue condition. This occurs despite the fact that the cue

15

provides a warning signal on all trials and for valid trials it provides information on where the target will occur. We discuss this result in more detail later (see page 000). In addition, right sided patients are worse on the contralateral side in the no cue condition than are the other groups. This is also true, but to a lesser degree for ipsilateral targets. With the exception of the no cue condition the other results are similar to what we have reported previously.

We now turn to the dual task performance. Five patients were run in the phoneme monitoring task by itself as well as together with the main task. The mean percentage of twenty trial blocks in which their report of the number of phonemes detected was correct was 68 when performed alone and 36 when combined with the visual task. For four patients no separate blocks of phoneme monitoring alone were collected and these patients had a mean of 70% detections in the dual task blocks.

Insert Fig 2 here

Figure 2 illustrates the effects of divided attention upon valid and invalid RTs in the spatial task. In Figure 2 the results are shown for patients using the phoneme monitoring task (upper two lines) and the counting task (lower two lines). There is a powerful main effect of dividing attention on phoneme monitoring $F(1,7) = 10.5, p < .01$, and attention interacts with the validity condition such that with

16

divided attention there is no validity effect for either task. This is the one place where interval interacts significantly. There is a strong cue by interval interaction $F(2,14)=6.0$, $p<.01$. This is illustrated in Figure 3 which shows the effect of divided attention on cue validity for the phoneme monitoring task at the long delay intervals. While the divided attention condition abolishes the validity effect at 100 millisecond, it is clearly present at the longer delays. Thus the effect of divided attention is to delay the persons ability to shift attention to the cue.

Insert Fig 3, here

Normal subjects may or may not show similar problems with divided attention. Figure 4 shows the same results for old and young normals

Insert Figure 4, here

in the phoneme monitoring task (solid lines) and for young normals in a previously reported study of counting backwards by threes (Posner, Cohen, Choate, Hockey & Maylor, 1984). In all cases there are effects of attention on primary task performance. However, for phoneme monitoring there is clearly no effect of divided attention on the size of the difference between valid and invalid trials. When we examine the counting backward task reported by Posner, Cohen, Choate, Hockey

17

and Maylor, 1984 we find a much larger effect of attention on the raw reaction times and also a clear interaction with validity of the same type as found in patients. In addition, Maylor (1983) has examined the same primary task with counting and has shown that one may or may not observe an interaction with validity depending upon the level of practice of the subjects.

The results illustrated in Figure 2 and 4 show that appropriate conditions divided attention can delay the ability of the cue to draw attention sufficiently so that neither normals nor patients show a validity effect at 100 millisecond. This suggests that the spatial orienting system must share some operations in common with the two secondary tasks, causing a delay of orienting when they are sufficiently difficult. It should be borne in mind that orienting toward a peripheral cue appears to be quite automatic in many situations (Jonides, 1981). Thus it is quite striking to see a loss of the validity effect for the patients at the 100 millisecond interval.

One might argue that the patients use the cue normally under divided attention conditions but no effect is shown because the language tasks delays the key press output. This view would regard the cue effects as being lost because the delayed response time allows the subject to shift attention from cue to target without it showing in RT. This view cannot explain the presence of a validity effect in the longer delay trials shown in Figure 3. In this condition there is still a delay in RT due to the secondary task but now a validity

18

effect only is clearly present. If the secondary task reduced the validity effect by delaying output in the 100 millisecond trials one would have to expect a similar effect at longer intervals since the overall delay in RT due to the dual task is still present. Instead it appears that the longer intervals provide a differential advantage on valid trials as one would predict if the secondary task retarded the patient's ability to use the cue.

Why should patients not orient to the cue at the short intervals in the dual task blocks? Clearly this must be due to the fact that they are engaged in processing the language task. If orienting to the secondary task uses the same parietal system as visual spatial orienting the patients should have specific problems with invalid contralateral targets. Evidence for an extinction-like reaction time pattern at 100 millisecond follows both from the view that the patient has oriented to the cue but cannot respond because of the secondary task or from the view that orienting has not taken place because the language task is engaging attention and uses the same parietal mechanism that is used for visual-spatial attention.

Figure 5 displays the significant triple order interaction between validity, attention and visual field ($F = 3.5 (2,14) p < .05$). The result indicates that under focussed attention conditions there are greatly lengthened RTs for contralateral invalid trials (extinction-like reaction time pattern), but there is no evidence of this under divided attention conditions. Thus attending to the

secondary task delays orienting, but does not do so by engaging the parietal system.

Insert Fig 5 about here

Discussion of Experiment 1

So far little has been said about the two dramatic results obtained in the no cue condition. First, the no cue blocks generally give faster RTs than the valid trials for both normals and left sided patients. Why should this be if, as we have argued, the advantage of valid over invalid trials is due to the presence of attention? Surely our view would hold that valid trials should be better than those without cues. This is particularly true because cued trials allow for increased alerting as well as for the advantages of selective attention to the cued location.

We were at first very puzzled by these results. Subsequently we have come to view them in light of the "emergent properties" argument (Duncan, 1982). In a simple RT task subjects often adopt a criterion of responding to any energy change. This works as long as there are no events to which they must inhibit a response. However, in the cued paradigm one must withhold a response to the cue. This could serve to raise the criterion for blocks in which there are cues over those in which no cues are given. We should be able to vary the relationship

20

between validly cued and no cue trials depending upon whether they occur in mixed blocks where a single criterion might be adopted or pure blocks in which different criteria would be allowed.

The second dramatic result was the poor performance of right sided patients in the no cue condition. Right sided patients are clearly worse than normals and left sided patients in the no cue condition while they appear virtually identical to the other groups on valid trials. Moreover, even in comparison with their own performance on valid trials right sided patients are poor in the no cue condition. Heilman has proposed that the right hemisphere is specialized for arousal and that when it is due to the hypoarousal resulting from its damage that such patients have special trouble in control of orienting. Our results suggest that left and right sided patients have equal problems with disengaging attention to deal with targets, but they raise the possibility that rights also have a special problem with maintaining alertness. This idea is based upon the supposition that since no cue trials do not provide a warning subjects must act to maintain a high level of alertness if they are to sustain fast RTs. If they fail to do so their performance will suffer in the no cue condition. If rights have difficulty in maintaining their alertness without a warning their performance would be at a special disadvantage in this condition.

Experiment 2

In order to test our conjectures about the nature of the data provided by the no cue condition we designed an additional set of experiments with young normals subjects. We first tested the idea that the relative speed of no cue vs valid trials depended upon the level of alertness of the subject. To do this we compared blocks of trials in which the time following the previous trial was 500 millisec (nearly optimal for alertness) with 5,000 millisec (a suboptimal interval for maintaining alertness). In a second experiment we tested the idea that the advantage of no cue over valid trials depended on adopting a low criterion during no cue blocks. We did this by comparing blocks in which no cue and cued trials were randomized so that no special criterion could be chosen for the no cue trials with pure blocks in which only no cue or only cued trials were given.

Method

Experiment 2a consisted of 12 young normal subjects run for two hours each. In experiment 2a subjects were run in four pure blocks. For two of the blocks the time following each trial before the next trial began was 500 millisec and for two it was 5,000 millisec. Within each condition one block consisted of no cue trials in which only a target was presented and the other block consisted of cued trials (80% valid and 20% invalid) in which the target followed the

cue equally often after 100 and 900 millise. Each block had 100 trials.

Experiment 2b consisted of 10 young normal subjects run in a single one hour session. The experiment was similar to 2a except that each subject ran in two mixed blocks of 160 trials. Within each mixed block there were 96 cued trials (50% valid) and 64 (uncued trials). One mixed block was run with 500 millise delay following the response (high alert) and one with 5000 millise delay (low alert).

Results

The results of experiment 2a are shown in Figure 6. The

Insert Fig. 6

pattern of results at high alertness was quite similar to that found with normal Ss and left sided patients in Figure 1. RTs were fastest in the no cue condition, intermediate in the valid cue condition and slowest in the invalid cue condition. The low alertness condition showed a pattern much more like the right sided patients. The valid trials are now slightly faster than the no cue condition with the invalid cue trials the slowest.

23

A statistical analysis of the overall data showed significant effects of alertness $F(1,11)=6.2$, $p<.05$; validity $F(2,22)=11.1$, $p<.01$; interval $F(1,11)=67.1$, $p<.01$; the interaction of validity with interval $F(1,11)=17.8$, $p<.01$ and the triple order interaction of alertness and validity with interval $F(2,22)=3.4$, $p<.01$.

The interaction between alertness and validity shown in Figure 6 was true at both intervals but was stronger with the 900 millise interval. This is mainly because the no cue trials show a smaller improvement with interval than do the cue trials, since there is no warning signal to mark the start of the trial. Figure 6 makes it appear as though alertness effects are present for both no cue and invalid trials. In fact while 11 of 12 subject have longer RTs in the low alert no cue condition than in the high alert no cue condition only 7 of 12 show an alertness advantage for invalid trials. Thus in a pure block of cued trials subjects appear to compensate for the suboptimal alerting quite well, but not in a pure block of uncued trials.

The results of Experiment 2b are shown in Figure 7.

Insert Figure 7 about here.

In this experiment alertness, interval and cue condition all had significant effects. There is also a cue by interval interactive due to the large improvement in RTs when a cue is present $p<.01$. In both

24

the alertness conditions there is an advantage of the valid trials over the invalid and no cue trials. The no cue trials have somewhat longer reaction times than the invalid trials particularly in the low alertness condition. In comparing the two experiments it is clear that mixing the block produces a specific disadvantage for the no cue trials.

Discussion of Experiment 2

These results illustrate the complexity of events that occur even in the relatively simple conditions of Experiment 1. Apparently the reaction time to a cued event depends in part upon the warning properties the cue provides, in part upon the location information provided by the cue, and in part upon the inhibition produced by raising the criterion to resist responding to the cue. Comparing valid to invalid trials allows one to hold the alerting and criterion effects relatively constant so as to compare the directional effect of the cue.

The two experiments generally confirm our conjecture that the advantage of uncued trials for normals in Experiment 1 results from adopting a lower criterion for these blocks. Apparently this is done based upon the property of the block and is not done, or at least not as well, on a trial by trial basis. This follows from finding that in mixed blocks no cue trials are much worse than valid trials. The

results also suggest that right sided patients have difficulty in maintaining a high enough level of alertness to perform well when a warning signal is absent. Put another way, the right sided patients fail to lower their criterion for no cue blocks. Since alertness effects usually result in changes in criterion these two statements may be equivalent. Our results with normals suggest that a failure to maintain alertness would account for the poor performance of right sided subjects in the no cue trials since they resemble performance of normals at a lowered level of alerting induced by a suboptimal intertrial interval.

It is also possible to ask whether normals show any differences in alerting when cues are presented directly to the right hemisphere. Previously (Heilman & Van Den Abell, 1979) have suggested that cues delivered to the right hemisphere from the left visual field would result in faster RTs than those that go directly to the left hemisphere. Figure 8 shows RTs from Experiment 2b as a function of which hemisphere first receives the target and/or cue. The lower two curves are for high alertness conditions while the upper two are for low alertness conditions. When no warning signal is provided subjects

Insert Figure 8 about here

have only the time from the last key press as marking the start of a trial. For warning intervals of 100 and 900 millisecc we plot only

valid trials where both cue and target go directly to the same hemisphere. The ANOVA for this breakdown shows that the only significant effects are those of alertness and warning interval. There is a small but non-significant trend for the left hemisphere targets to be better under the high alert conditions than right hemisphere targets. This trend is in the opposite direction from what would be predicted from a right hemisphere advantage for alerting. There is no hint that the alerting functions differ for the two hemispheres. Thus while our patient evidence suggests that right hemisphere damage has a great affect in maintaining alertness they do not confirm that this effect can be found in normals by varying the location of the warning cue.

Conclusions

Parietal Deficit

The present experiments confirm previous findings concerning the visual-spatial attention system. When the attention of patients with parietal lesions is summoned to a visual cue they have a powerful deficit in handling contralateral targets. When attention is at the cued location or when the target is ipsilateral to the lesion, a much smaller or no deficit over the performance of age related controls is found. This strongly suggests that the deficit due to parietal lesions is specific to the ability to disengage from a stimulus once attention has been committed.

The current study indicates that the right and left parietal lobe are symmetric for this function, because the advantage of valid over invalid trials is similar for the two groups (see Figure 1). There are a number of clinical and experimental findings (De Renzi, 1982) showing that right sided patients show more dramatic effects of parietal lesions in the spatial domain. Our current data suggest that these dramatic differences may result from factors other than the directional operation of the parietal lobes (see alerting below). Independent Module?

Visual spatial attention is one form of selectivity by which information reaches area(s) responsible for conscious report. The parietal damage must involve only a pathway involved in reaching conscious report. This is established by the relatively intact performance of these patients once attention has been summoned (valid trials) even to a target location which is contralateral to the lesion. Thus some system can compensate for the relative inefficiency of the damaged parietal lobe, arguing that higher level attentional systems must be in tact.

How does this visual-attention pathway relate to pathways involved in dealing with other aspects of attention? Experiment 1 shows that processing language stimuli (phoneme monitoring or counting backward) delays orienting to the spatial cue. Since the act of orienting requires no overt movement that might interact with the secondary task it seems reasonable to suppose that attending to non-spatial stimuli

interferes directly with the system that shifts visual attention. We know from much other work on interference effects (Posner, 1978) that tasks like counting backward or phoneme monitoring also interfere with most other types of cognitive operations. Moreover, this interference is quite time locked. It is not as though the secondary task completely inhibits the attention shift it simply delays it so that what is usually quite strong at 100 millisec is no longer complete in that time. In addition the secondary task performance itself suffers from competition from the primary attention shifting task. These properties suggest that there is a common command system needed both to issue commands to produce spatial orienting and for some aspects of monitoring (e.g. incrementing the count when a target occurs) (Duncan, 1980).

If one accepts the interference effects found in the visual-spatial orienting task in our patients as evidence for such a common attention system what can we say about this system? Our main finding is that the anatomy of the common system must be different than that found for the visual-spatial pathway. This is because engaging the subject in a language task produces no specific deficit for targets contralateral to the lesion. Since it appears that damage to the parietal lobe manifests itself in a specific deficit in disengaging to deal with contralateral targets it follows that the engaging attention to the language task must not involve the parietal mechanism involved in visual-spatial attention.

In short our evidence favors two distinct neural systems a specific visual-spatial system involving the parietal lobe and a more general system common to both visual-spatial and language attention. It seems likely that the more general system operates as a command system to allow orienting of visual-spatial or other forms of attention. Since we know that the failure of the visual-spatial system means that the patient will be unaware of the target it appears that this second system may be responsible for the specific operations underlying our ability to report the stimulus subjectively.

From previous work in cognitive psychology (Marcel, 1983) it appears that under some conditions a stimulus may be processed quite deeply including producing semantic activation without subjects being aware of the stimulus. In anatomical terms this suggests that a good deal of processing by posterior areas of the brain can occur without the subjects being conscious of the event.

The visual spatial parietal system is closely connected to prefrontal association cortex (Mesulam, 1981; Schwartz, & Goldman-Rakic, 1984). Moreover, when areas of the posterior parietal cortex are active metabolically during cognitive tasks there is some evidence that corresponding areas of the frontal cortex are also active (Rowland, 1985). These findings all suggest that areas of the prefrontal association cortex might be of special importance to the common system we have been discussing.

Alerting

How do the results concerning alerting fit into the operation of selective systems? First our experiments show that alerting effects are quite independent of the direction of attention. This view arose first based on experiments performed many years ago in which the effects of primes and warning signals were shown to have additive effects on improvement in reaction time (Posner & Boies, 1971). At that time it was pointed out that the source of alerting effects was likely to be subcortical arousal systems since EEG evidence of alerting was found in both hemisphere of split brain monkeys even when the signal went only to one hemisphere (Hillyard & Gazzaniga, 1973). These subcortical systems influence stimulus processing by acting on a higher level attention system rather than upon input pathways (Posner, 1975). This argument was based on the evidence for a criteria shift because error rates increase usually accompany the faster RTs to warning signals.

Our current data extend this view by showing that right sided patients have special difficulty in maintaining a high level of alertness during a brief delay between trials. This difficulty does not affect their ability to use warning signals or their ability to shift attention in the cued direction.

In clinical tasks and daily life right sided patients often manifest more severe spatial effects from lesions than do left sided patients. Recall that deficits in alerting affect higher level attention systems not the activation of pathways by which information is accumulated (Posner & Boies, 1971; Posner, 1978). In terms of our present argument this would be an affect upon the attention command system rather than or more strongly than upon the directional selective system. The consequence would be to make more sluggish commands to activate the posterior system. In that case without the presence of specific cues the right sided patients might show a deficit performance in natural and clinical situations. In accord with this possibility recent evidence has accumulated that the right hemisphere may be closely involved in the arousal of cortex by norepinephrine and serotonin than is the left hemisphere (Tucker & Williamson, 1985).

Hierarchical Distributed Network

Mesulam (1981) has attempted to distinguish between several views of how brain systems function to control spatial attention. These general views are what he calls center theories, network theories and wholistic theories. The center theory regards spatial attention as the property of a single system. The network theory views components of the function as assigned to quite distinct neural systems. The

wholistic theory regards attention as a general property of the brain. The data he reviews favor a network theory. Our data also support a network approach. The anatomical separation between the visual spatial attention system and the higher level common system argues against a single center. While the degree of anatomical specificity found for visual spatial attention argues against any wholistic view. However, our findings suggest two additions to Mesulam's view.

First, we are in a position to specify what the components are for the simple act of covert orienting of spatial attention. The components consist of disengaging attention from its current focus, moving attention and engaging the target. The disengage function appears to be controlled by the parietal lobe when disengaging from a visual/spatial location is involved but not in cases when disengaging from other cognitive operations. The "move" function is affected by midbrain lesions which involve the superior colliculus among other areas (Posner, Choate, Rafal, & Vaughan, 1985). These midbrain structures also show the property of resisting reorienting to an already attended location (inhibition of return). In the current study we show the role of a higher level attention system in producing the signal required to engage visual/spatial attention. When this higher level system is already occupied there is a clear reduction in the efficiency of engaging a visual location. We can only speculate that the attentional system, common to language and spatial location, probably lies anterior to the parietal system and includes the areas

of the frontal lobe which have been shown to be closely connected anatomically to the parietal system (Mesulam, 1981).

Our results favor a second modification of Mesulam's network idea which might be called a heirarchial network. We find that some neural systems related to attention seem to coordinate or control the action of other systems. Thus within the visual spatial system the parietal mechanism must act to disengage attention prior to its being moved to the target. The midbrain centers shown to affect the "move operation" thus are controlled by the operation of the cortical centers responsible for the "disengage operation." Similarly it appears that the posterior areas responsible for spatial orienting as a whole are controlled by a higher level system.

We believe that such a heirarchical network viewpoint is very much in accord with the general spirit of findings both in neurophysiology and cognitive psychology. In neurophysiology the operation of higher centers which act to tonically inhibit lower systems and act through feedforward mechanisms to produce phasic potentiation of activity are well known principles of the organization of nervous systems (Mountcastle, 1978). In cognitive psychology, central attention theories offer a necessary means of coordination among a number of semi-independent codes which are activated by input (Keele & Neil, 1978; Posner, 1978; Treisman & Gallade, 1980).

There are mechanisms of selection within each sensory system (Hillyard & Kutas; Naatanen, 1982) which serve to gate some

information and potentiate other information sources. At the level of the cortex information from different sensory systems (e.g. vision and audition) must be integrated when it relates to the same cognitive system (e.g. spatial location, object identification, language). Indeed we (Posner and Henik, 1983) compared the effectiveness of stimuli in producing mutual interference and facilitation when both were within the same modality but in different cognitive systems with when they were within the same cognitive system but in different modalities. Our results show that, at least in the circumstance of our test, stimuli within the same cognitive system produce more mutual interaction than those that share only input modality. This point argues for a level of selection that integrates separate sensory systems.

It seems reasonable to suppose that stimuli in different cognitive systems (e.g. language and spatial location) must also be coordinated at some level. The current results show that the principle of distributed but heirarchical networks can be applied to this problem. Although the disengage operation appears specific to mechanisms within a cognitive system, there also appear to be a general cross-cognitive system mechanism that is required to permit selection to occur within any one cognitive system. When this central mechanism is engaged in a language operation there is a clear reduction in efficiency of spatial orienting. The heirarchical network idea allows us to see why damage to particular location in the

CNS produces deficit in operations specific to one cognitive system (e.g. spatial orienting, language) while damage to other locations may produce more widespread attentional deficits that are not specific to any cognitive system.

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37

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38

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42

Figure Captions

Figure 1 Mean RTs as a function of cue condition in the single task blocks of Experiment 1. Data are for young and old normal groups and patients with right (R) and with left (L) parietal lesions. For the patient groups the data are separated for targets on the side of the lesion (ipsilateral) and on the opposite side (contralateral).

Figure 2 Mean RT for valid and invalid trials for a spatial attention task when performed alone (focus) and when done with two types of secondary tasks monitoring for phonemes and counting backwards.

Figure 3 Mean RTs for patient groups with long delay trials (500 or 1,000 msec between cue and target) for both focus and divided blocks as a function of cue validity.

Figure 4 Mean RTs for young and old normals for spatial attention alone and dual task divided attention. Circles and triangles involve monitoring as the secondary task. Squares refer to data from Posner et. al. 1984 for counting backward by 3 as the secondary task.

43

Figure 5 Magnitude of extinction like reaction time pattern (contralateral minus ipsilateral reaction times) for single (focus) and dual (divided) task blocks of Experiment 1.

Figure 6 RTs as a function of cue conditions for pure blocks of cued or uncued trials conducted with long (low alert) or optimal (high alert) intertrial intervals. Experiment 2a.

Figure 7 RTs as a function of cue conditions for blocks of mixed cue and no cue trials with long (low alert) and optimal (high alert) intertrial intervals. Experiment 2b.

Figure 8 Warning signal function for trials in which the cue and/or target are presented to the left visual field (right hemisphere) and those for which they are presented to the right visual field (left hemisphere). Data are from no cue and valid trials of Experiment 2b.

44

Footnotes

1. This research was supported in part by NIMH grant RO1-3053-02 and in part by the Office of Naval Research Personnel and Training Branch under Contract No. N 00014-83-R-0601.

2. Currently at the Department of Neurology, Box 8111, Washington University School of Medicine, 660 S. Euclid Ave., St. Louis, MO 63110.

3. Now at Department of Psychology, University of New Hampshire, Durham, NH

4. Now at Department of Psychology, University of Utah, Salt Lake City, UT.

45

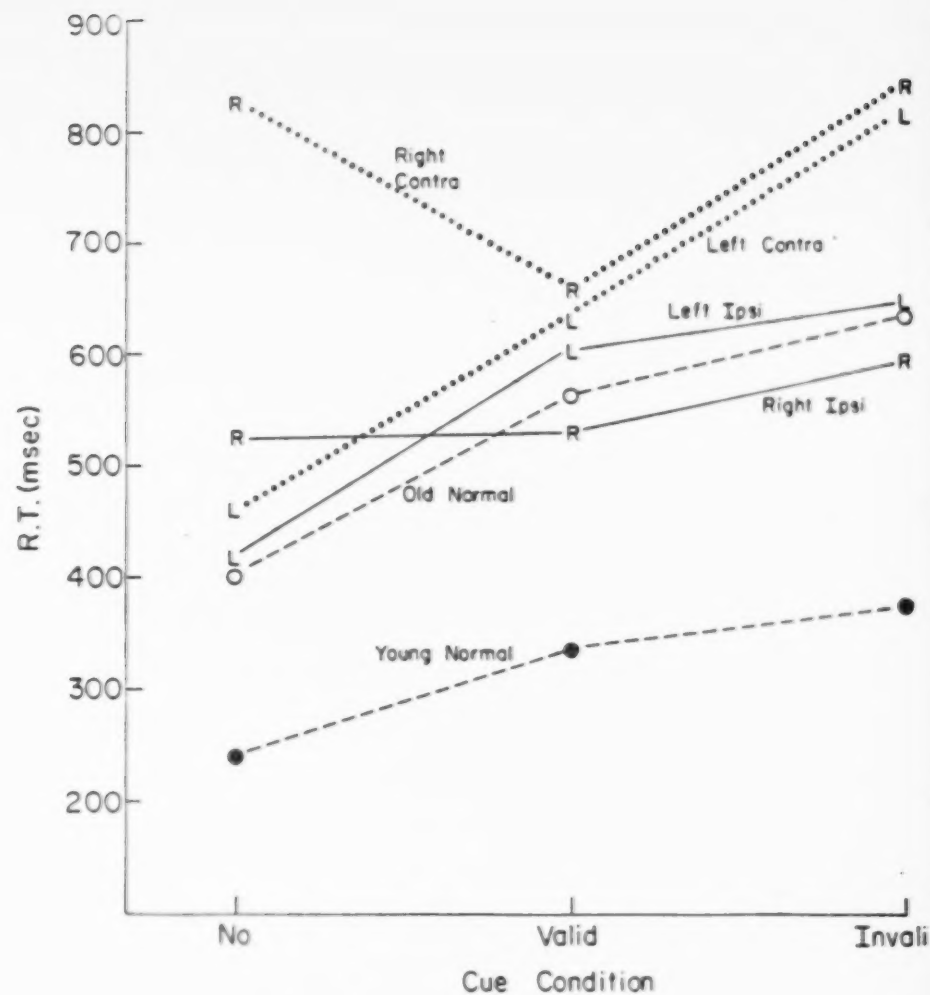


Figure 1

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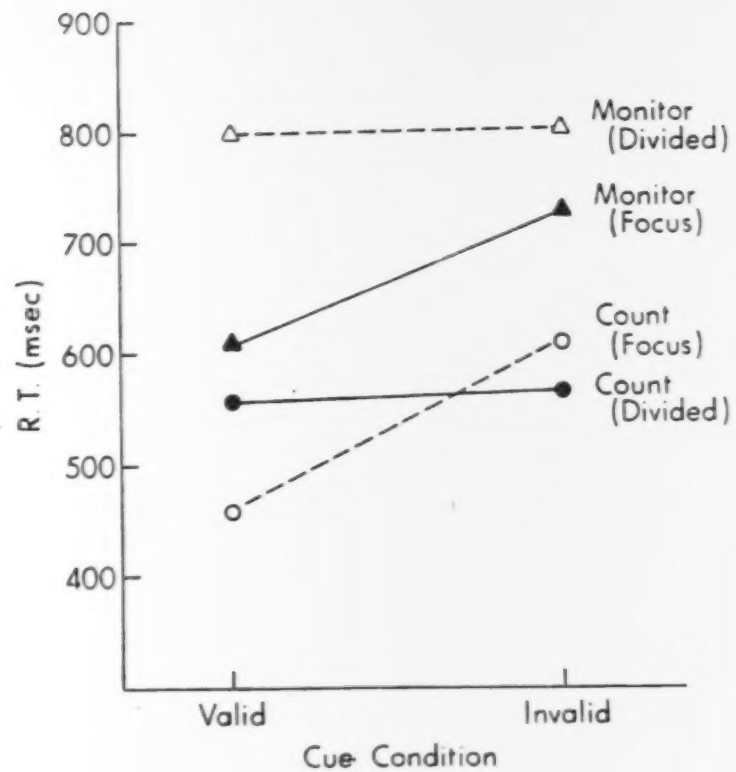


Figure 2

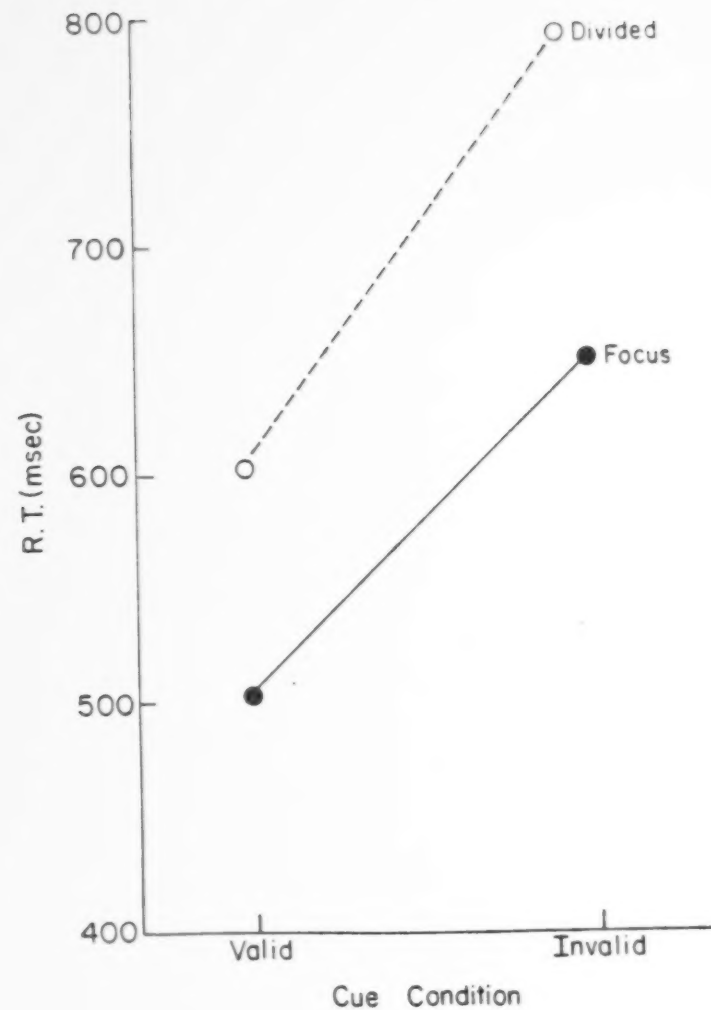


Figure 3

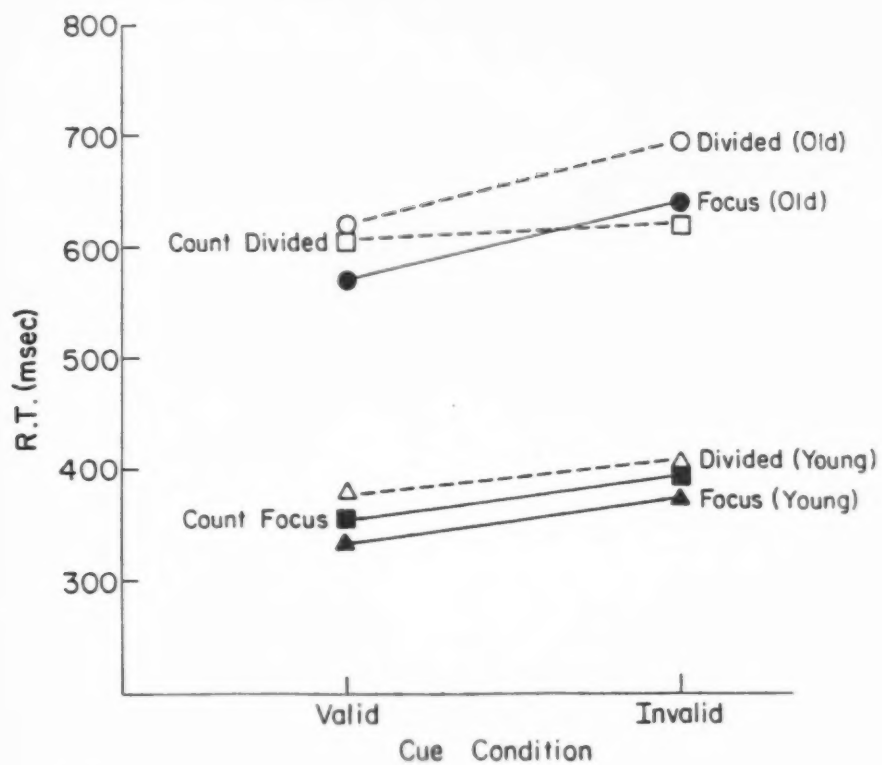


Figure 4

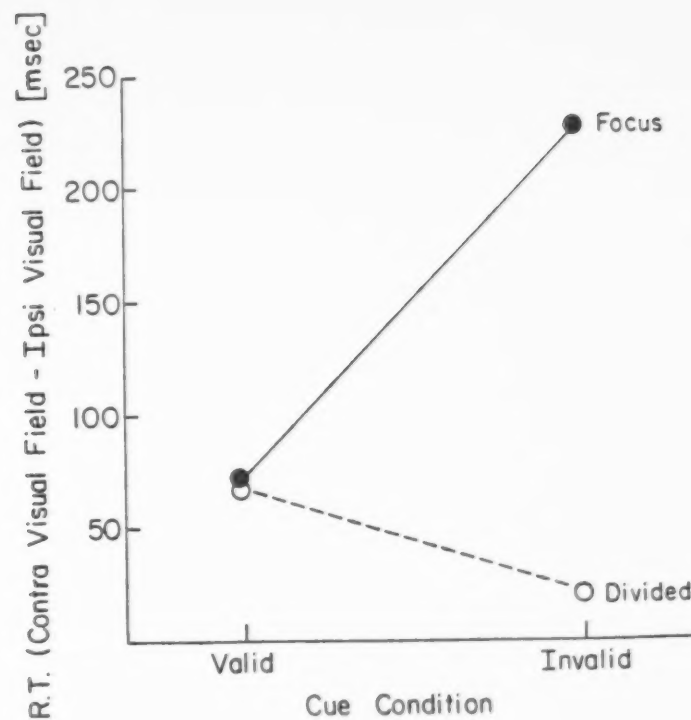


Figure 5

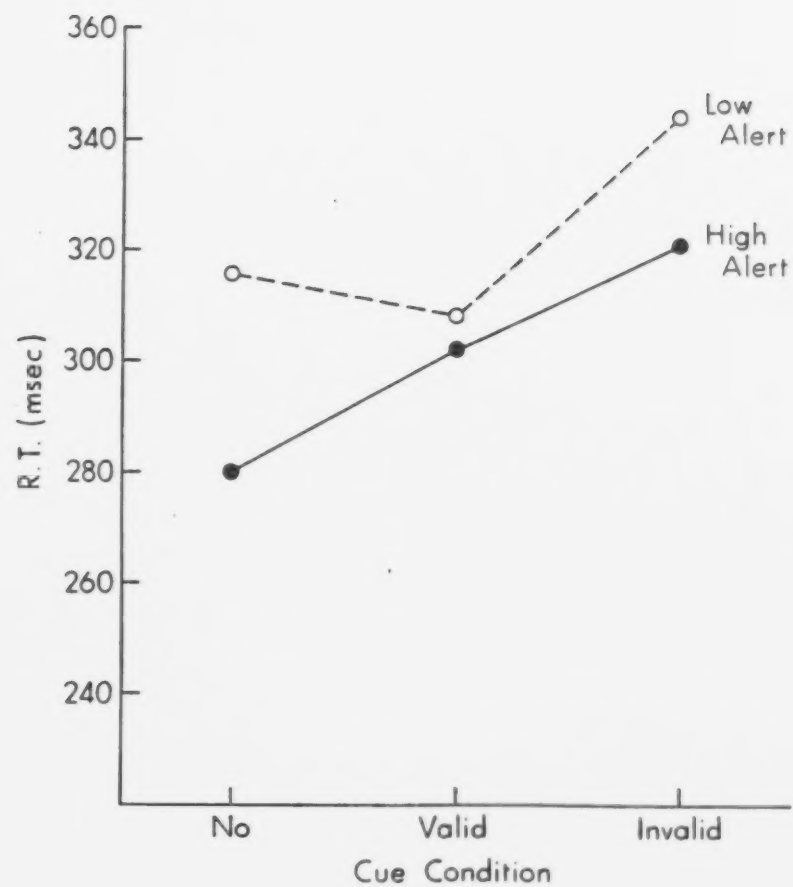


Figure 6

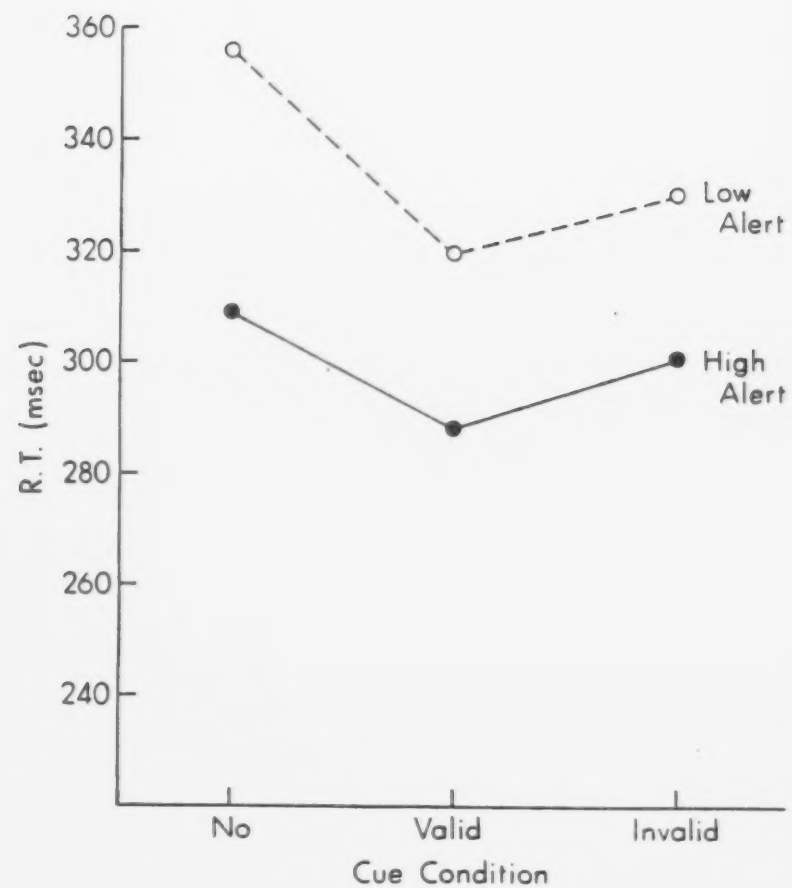


Figure 7

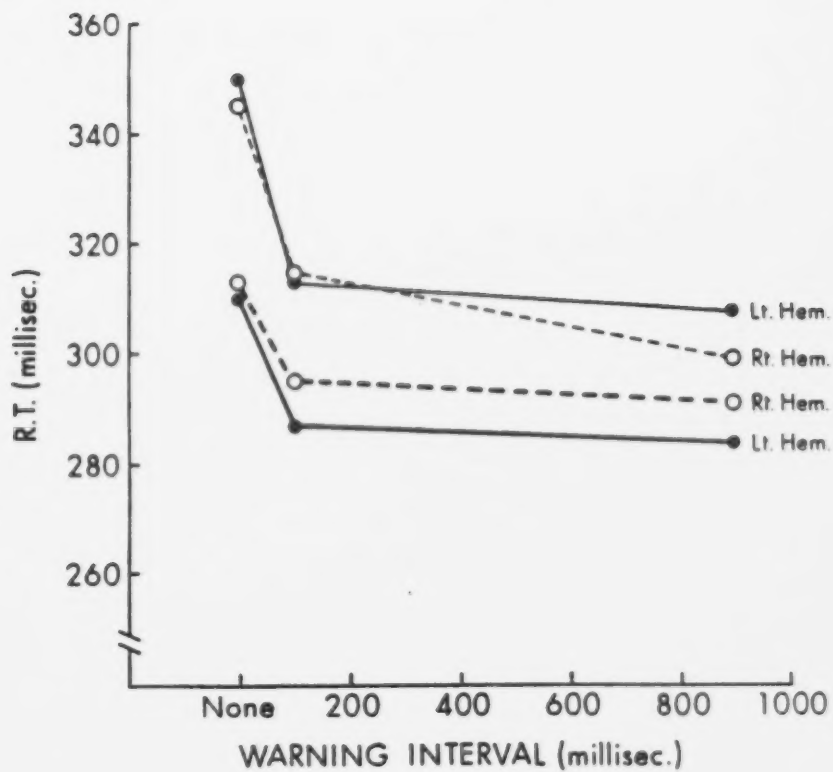


Figure 8